# APPENDIX C: CHARACTERISTICS OF GENERATED UWB SIGNALS

The following sections describe details of UWB signal generation and provide APDs for each of the signal permutations used in these measurements.

## C.1 Signal Description

Each of the UWB signals used in these measurements was generated using a UWB pulser triggered by either an AWG or custom designed 2%-RRD trigger circuit. Two different pulsers were utilized, each described in Appendix B.2. All single source measurements were performed using the Time Domain Corporation PG-2000 unit, and all aggregate measurements were performed using three Time Domain Corporation PG-2000 units and three MSSI TFP-1000 units. All of the 2%-RRD UWB signals with a PRF of 3 MHz or greater were generated using a custom built dithering trigger circuit.

Table C.1.1 lists parameters for each of the 39 UWB signals used for these measurements. The first 32 UWB signals in the table were used for single source conducted measurements; the remaining 7 signals were used for radiated and/or aggregate measurements.

Table C.1.1.Characteristics of Generated UWB Signals

| PRF (MHz) | Pulse Spacing Mode | Duty Cycle (%) | PRL[1] Spacing (kHz) | Spectral Line Placement [2] (MHz) | LSNB [3] (Hz) | LSS [4] (Hz) | Nearest SN to L1 [5] (MHz) |
|---|---|---|---|---|---|---|---|
| 0.1 | UPS | 100, 20 | N/A | 1575.570571 | N/A, 500 | N/A, 50 | N/A |
| 1 | UPS | 100, 20 | N/A | 1575.570571 | N/A, 500 | N/A, 50 | N/A |
| 3 | UPS | 100 | N/A | 1575.570571 | N/A | N/A | N/A |
| 5 | UPS | 100, 20 | N/A | 1575.570571 | N/A, 500 | N/A, 50 | N/A |
| 10 | UPS | 100 | N/A | 1575.570571 | N/A | N/A | N/A |
| 20 | UPS | 100, 20 | N/A | 1575.570571 | N/A, 500 | N/A, 50 | N/A |
| 0.1 | OOK | 100, 20 | 0.059 | 1575.570571 | N/A, 500 | N/A, 50 | N/A |
| 1 | OOK | 100, 20 | 0.017 | 1575.570571 | N/A, 500 | N/A, 50 | N/A |
| 5 | OOK | 100, 20 | 0.089 | 1575.570571 | N/A, 500 | N/A, 50 | N/A |
| 20 | OOK | 100, 20 | 0.357 | 1575.570571 | N/A, 500 | N/A, 50 | N/A |
| 0.1 | 50%-ARD | 100, 20 | 0.098 | N/A | N/A, 500 | N/A, 50 | 1560 |
| 1 | 50%-ARD | 100, 20 | 0.997 | N/A | N/A, 500 | N/A, 50 | 1600 |
| 3 | 50%-ARD | 100 | N/A | N/A | N/A | N/A | 1650 |
| 5 | 50%-ARD | 100, 20 | 4.88 | N/A | N/A, 500 | N/A, 50 | 1500 |
| 20 | 50%-ARD | 100, 20 | 19.5 | N/A | N/A, 500 | N/A, 50 | 2000 |
| 0.1 | 2%-RRD | 100, 20 | 0.25 | N/A | N/A, 500 | N/A, 50 | 1615 |
| 1 | 2%-RRD | 100, 20 | 1.25 | N/A | N/A, 500 | N/A, 50 | 1900 |
| 3 | 2%-RRD | 100, 20 | N/A | N/A | N/A | N/A | N/A |
| 5 | 2%-RRD | 100, 20 | N/A | N/A | N/A | N/A | N/A |
| 10 | 2%-RRD | 100, 20 | N/A | N/A | N/A | N/A | N/A |
| 20 | 2%-RRD | 100, 20 | N/A | N/A | N/A | N/A | N/A |

[1] Pattern Repetition Lines (PRL) refer to spectral lines generated due to a repetition of the pulse pattern. (See Section C.2 for a complete discussion.)

[2] Lines due to the pulse repetition period are spaced at intervals equal to the reciprocal of PRF, but for each UWB with these spectral lines, the PRF is adjusted slightly so that one of the lines occurs at 1575.570571 MHz.

[3] Line Spreading Null-to-null Bandwidth (LSNB) refers to the null spacing of the convolving $sinc^2$ function as a result of gating, where the null-to-null bandwidth is equal to 2 times the reciprocal of the gated-on time. (See Section 4.1.2 for a complete discussion.)

[4] Line Spread Spacing (LSS) refers to the spacing between lines of the convolving $sinc^2$ function as a result of gating, where the distance between lines is equal to the reciprocal of the gating period. (See Section 4.1.2 for a complete discussion.)

[5] Spectral Node (SN) refers to a spectral feature due to the placement of the position of pulses within discrete bins. (See Section C.2 for a complete discussion.)

## C.2 Residual Spectral Effects due to Signal Generation

Because the pattern of pulse spacing, whether it be OOK or dithering, is stored in the memory of an AWG and because that memory has limits with regard to size, the same pattern has to be repeated at periodic intervals. This pattern repetition results in signal power being gathered up into spectral lines with a spacing equal to the reciprocal of the period of the pattern. For those UWB cases where we would expect real world signals to have no pattern repetition, the pattern is made as long as possible so that the spectral lines are spaced very close together, and therefore, have negligible impact on the receiver. For purposes of brevity, we call these spectral lines Pattern Repetition Lines (PRL).

Also because of the limitations of memory size and sample rates of the AWG, the location of pulses (within the context of dithering) has to be confined to a limited number of discrete time bins. This is illustrated in Figure C.2.1 for the case of 50% clock-referenced dithering, in which the pulse position can be assigned to any of 19 possible discrete positions within the first 50% of the interval between reference clock periods (*t* is the size of the bins, in units of time). As opposed to a continuum of possible pulse positions, this discrete binning results in some additional spectral features worth noting. Figure C.2.2 demonstrates what we have described as a spectral node (SN), in which there is a depression in the spectral noise and the emergence of spectral lines. The spacing of these spectral nodes is directly related to the bin size *t*, where the distance between spectral nodes is 1/*t*. This phenomenon is described in greater detail in Appendix D (Theoretical Analysis of UWB Signals Using Binary Pulse-modulation and Fixed Time-base Dither). For these measurements, efforts were specifically made to place these spectral nodes in a location other than the L1 and L2 bands.

The custom built 2%-RRD circuit is analog, and therefore signals generated using this circuit do not have PRLs or SNs characteristic of signals generated digitally with an AWG.

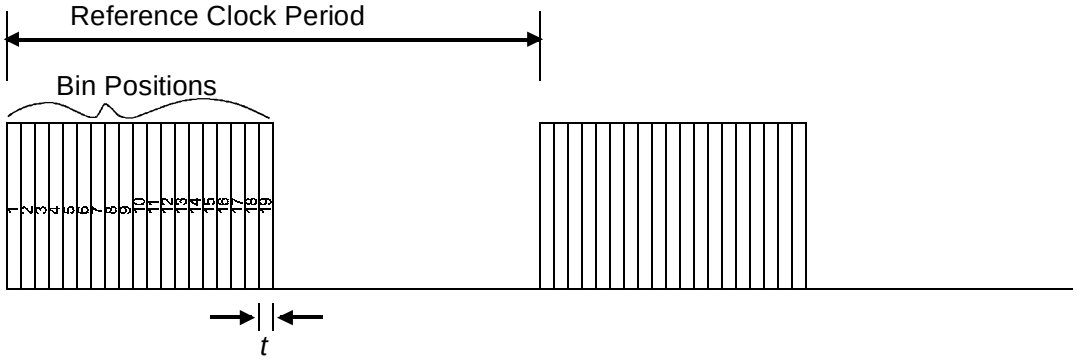


Figure C.2.1. Discrete binning of pulse position for clock referenced dithering.

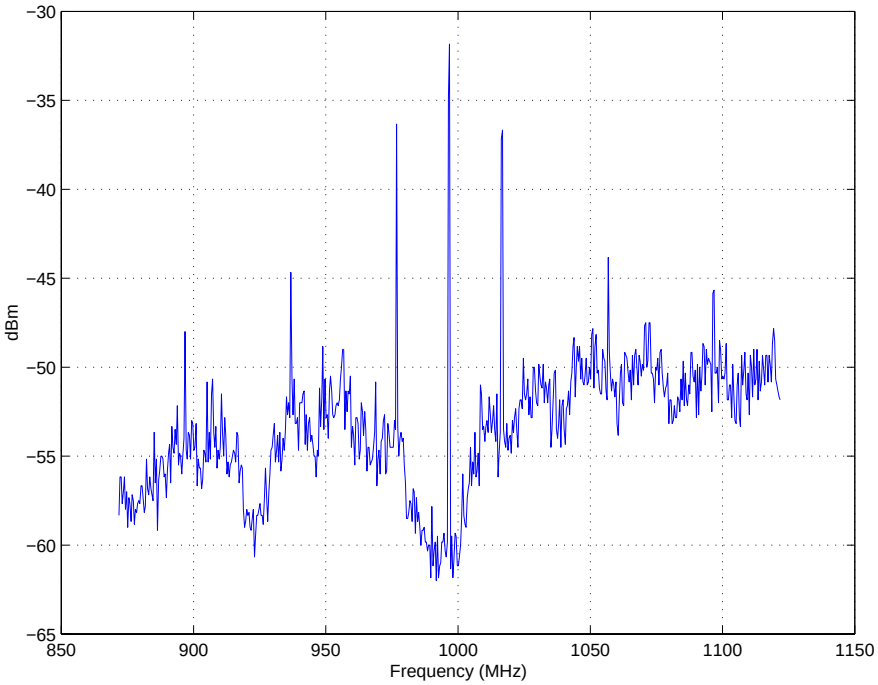

Figure C.2.2. Spectral lines due to discrete binning of pulse position.

## C.3 APDs Characteristics of UWB signals

Figures C.3.1 through C.3.29 and Figures C.3.30 through C.3.31 show APDs for each of the 32 different single source UWB permutations and the 9 different aggregate signal scenarios respectively. Two different measurement bandwidths were used – 3 MHz and 20 MHz – representing a bracketing of a wide range of bandwidths. For the single source permutations, several different groupings for composite plots are shown. The four different UWB signals, each representing a different PRF, are plotted as a composite of all the different permutations of pulse spacing modes and gating. Along the other dimension, each of the pulse spacing modes (including gated and non-gated) are plotted as a composite of each of the 4 different PRFs.

For each APD, the mean power is normalized to 0 dBm/20 MHz. Note that mean power for gated signals includes both the gated on and off time. This is in contrast to the power representation of gated signals for operational and observational metrics in Section 6.

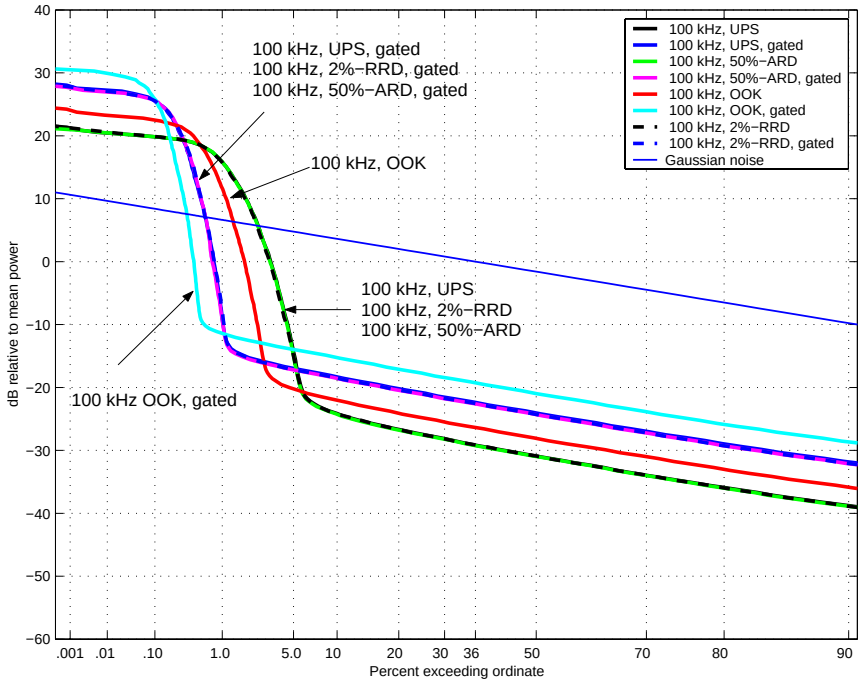


Figure C.3.1. APDs of 100-kHz PRF UWB signals measured in a 3-MHz bandwidth.

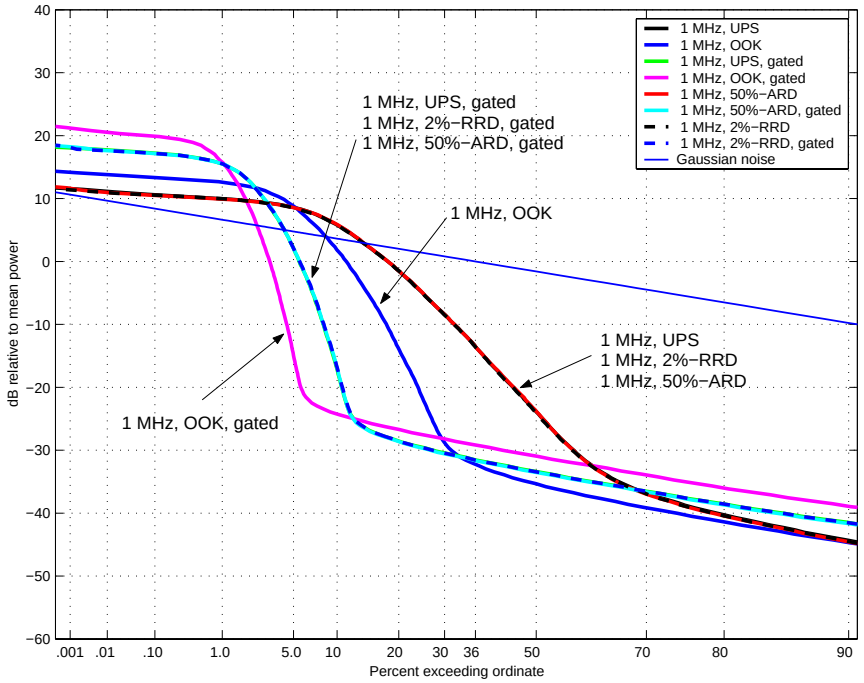


Figure C.3.2. APDs of 1-MHz UWB signals measured in a 3-MHz bandwidth.

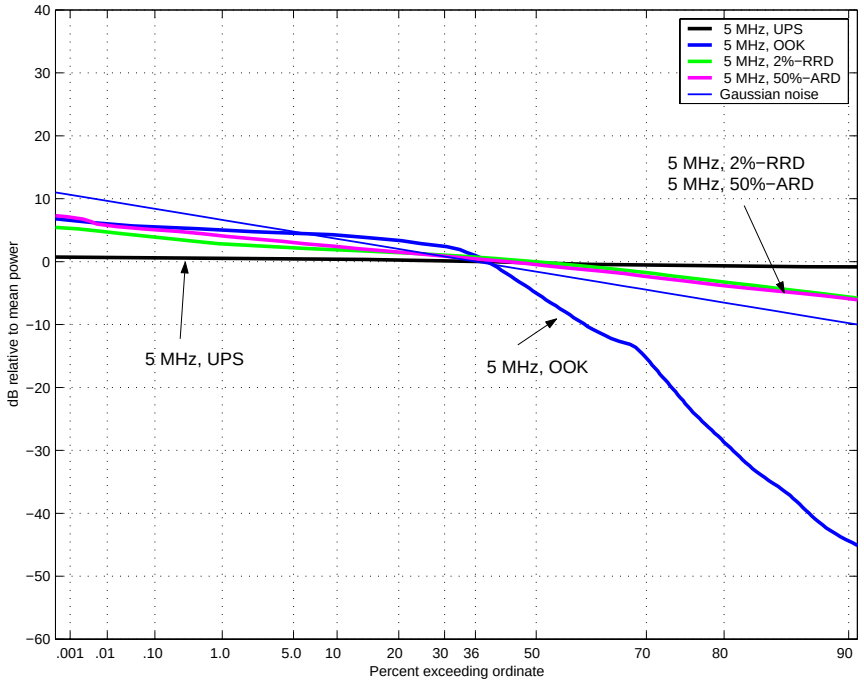


Figure C.3.3. APDs of 5-MHz PRF, non-gated UWB signals measured in a 3-MHz bandwidth.

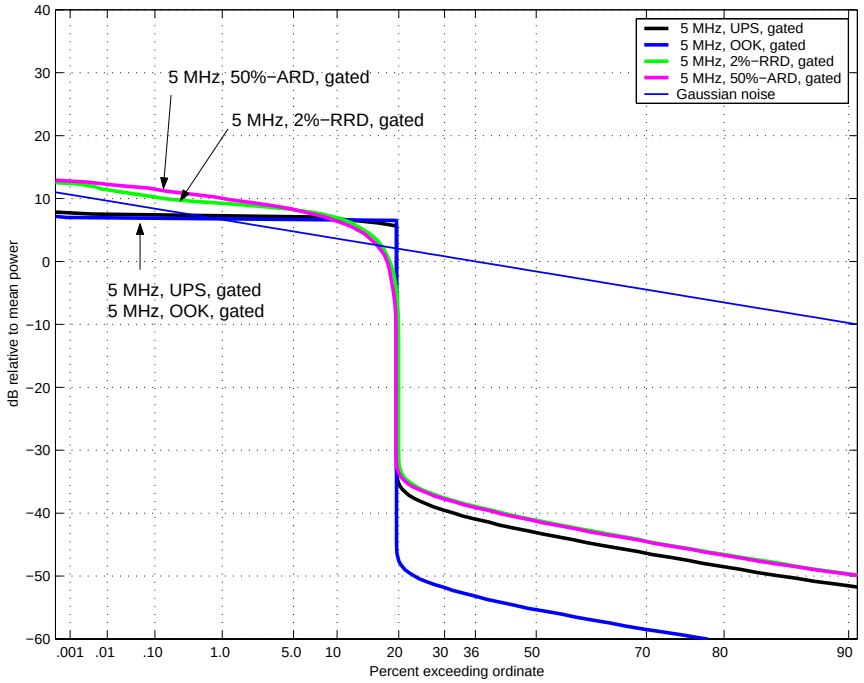


Figure C.3.4. APDs of 5-MHz PRF, gated UWB signals measured in a 3-MHz bandwidth.

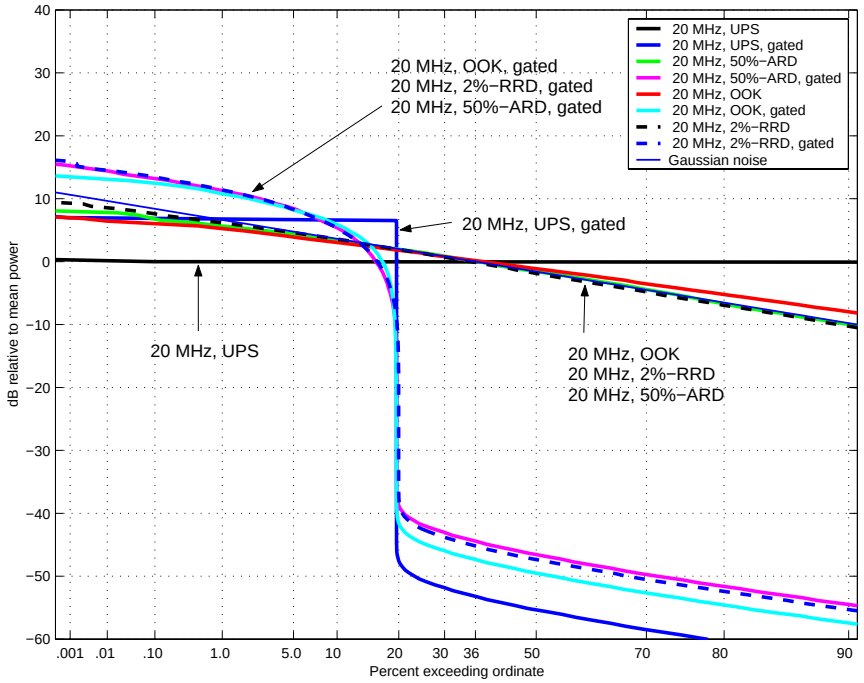


Figure C.3.5. APDs 20-MHz PRF UWB signals measured in a 3-MHz bandwidth.

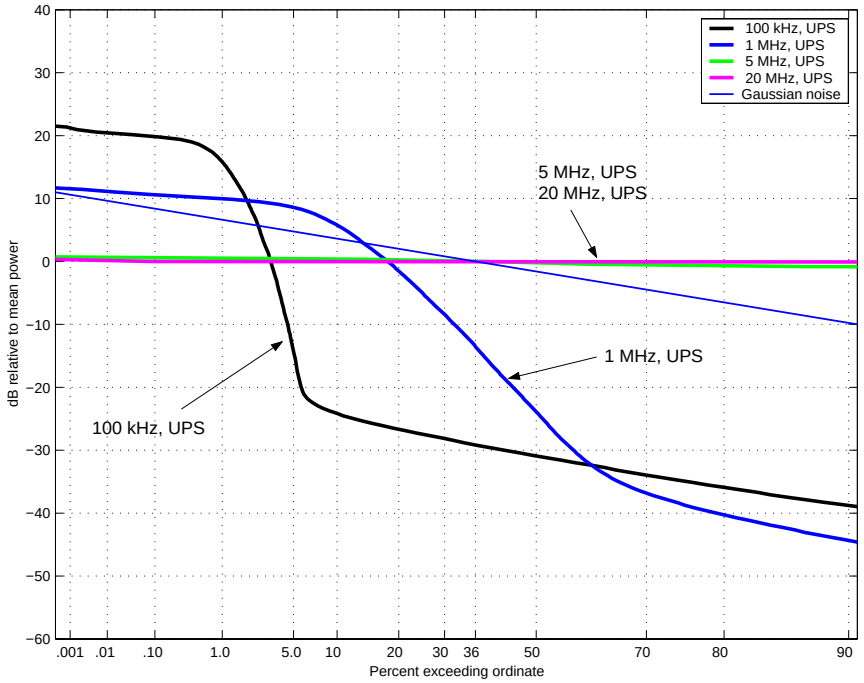


Figure C.3.6. APDs of UPS, non-gated UWB signals measured in a 3-MHz bandwidth.

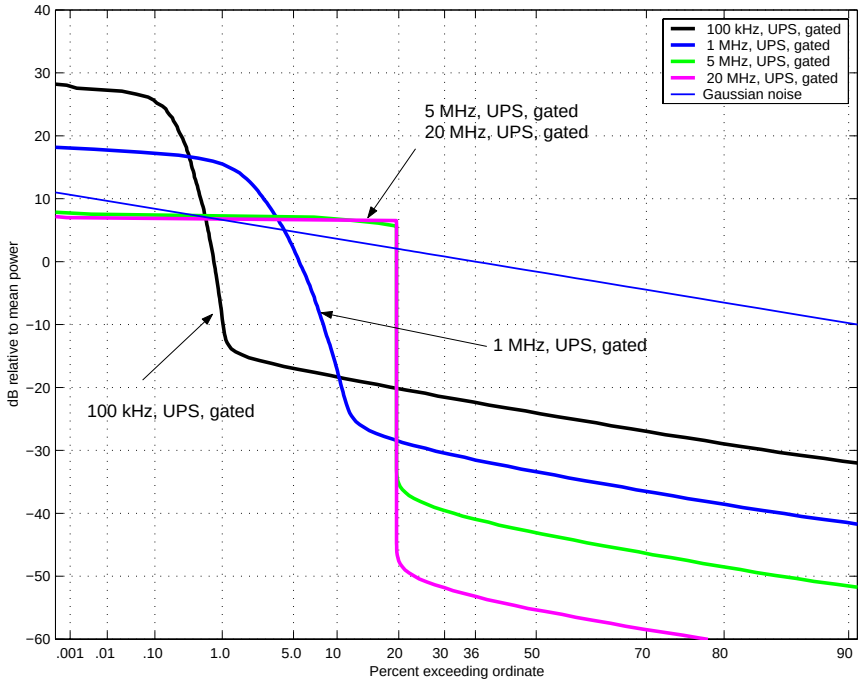


Figure C.3.7. APDs of UPS, gated UWB signals measured in a 3-MHz bandwidth.

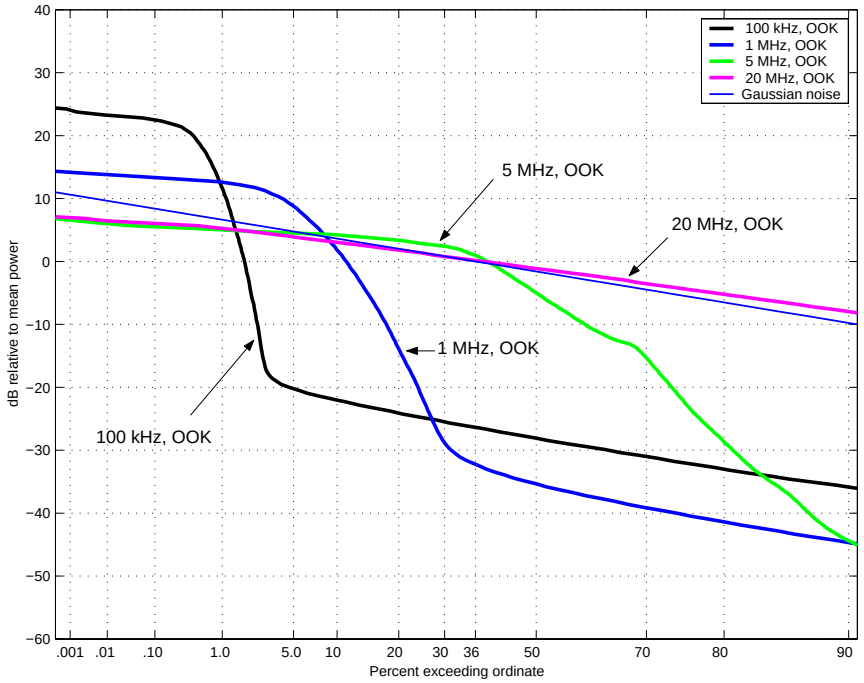


Figure C.3.8. APDs of OOK, non-gated UWB signals measured in a 3-MHz bandwidth.

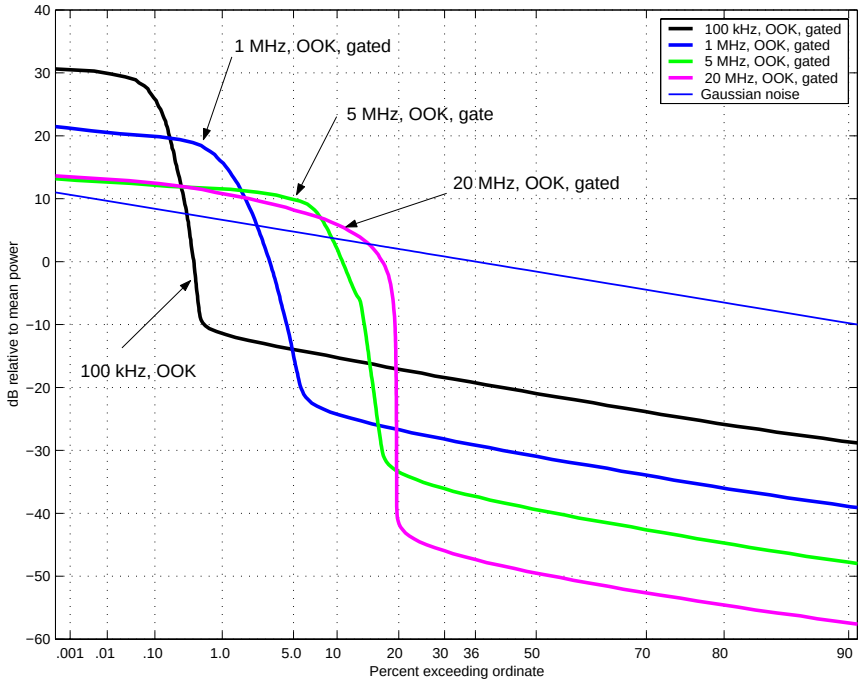


Figure C.3.9. APDs of OOK, gated UWB signals measured in a 3-MHz bandwidth.

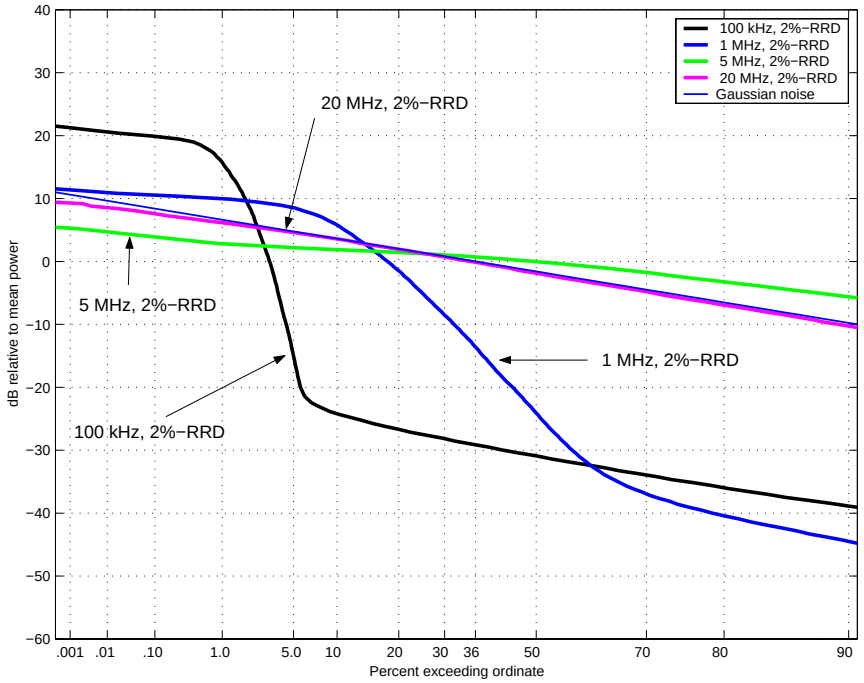


Figure C.3.10. APDs of 2%-RRD, non-gated UWB signals measured in a 3-MHz bandwidth.

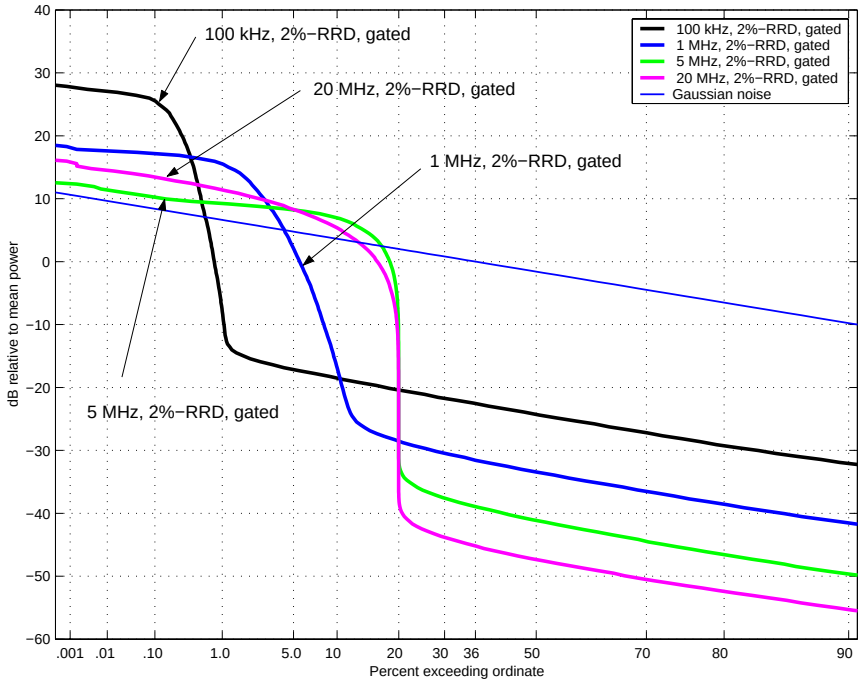


Figure C.3.11. APDs of 2%-RRD, gated UWB signals measured in a 3-MHz bandwidth.

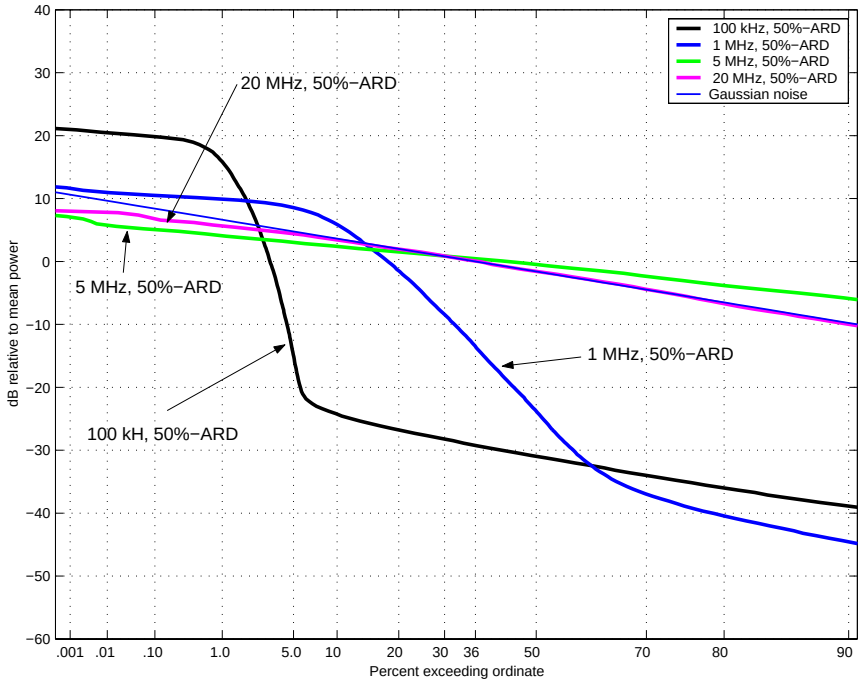


Figure C.3.12. APDs of 50%-ARD, non-gated UWB signals measured in a 3-MHz bandwidth.

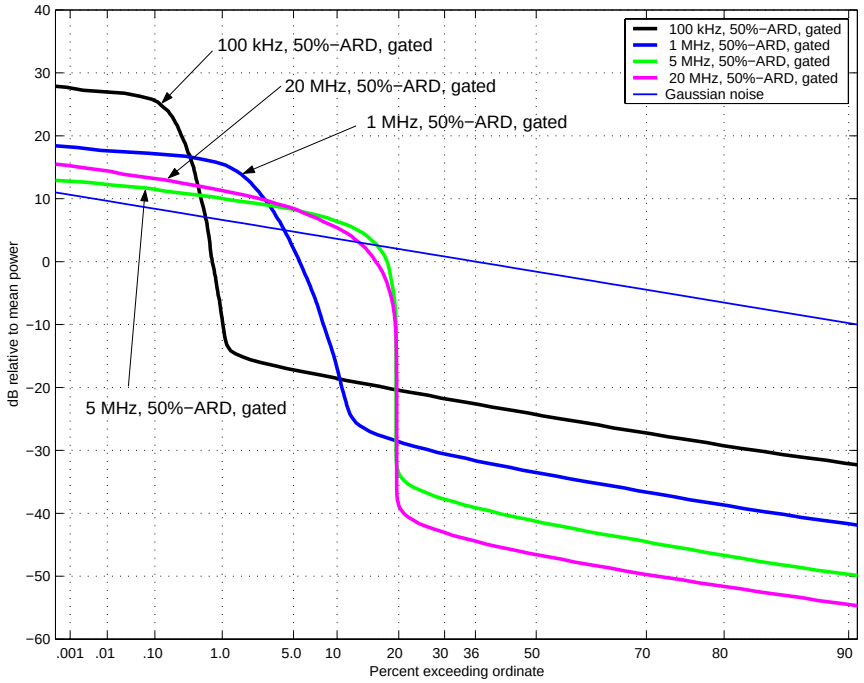


Figure C.3.13. APDs of 50%-ARD, gated UWB signals measured in a 3-MHz bandwidth.

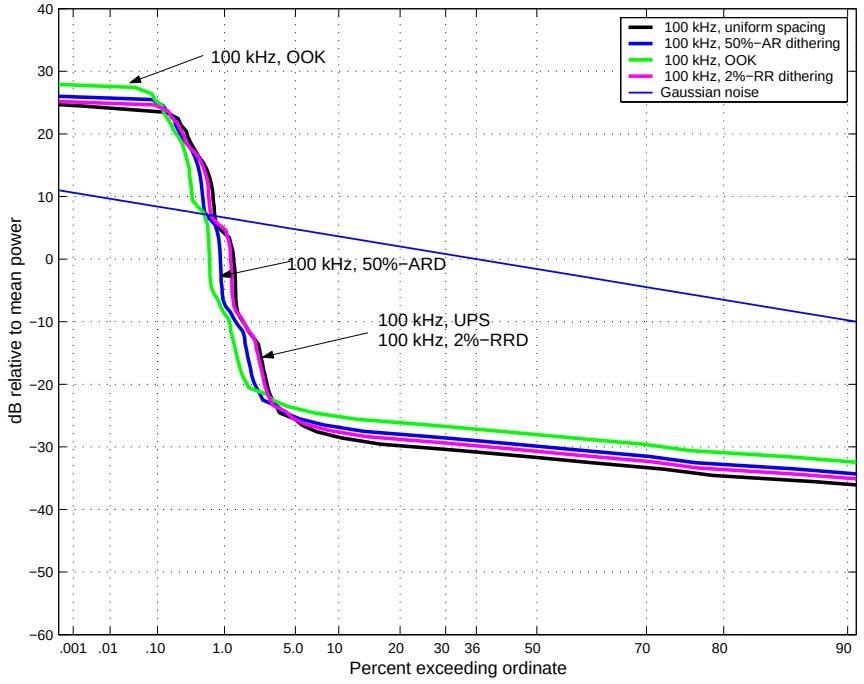


Figure C.3.14. APDs of 100-kHz PRF, non-gated UWB signals measured in a 20-MHz bandwidth.

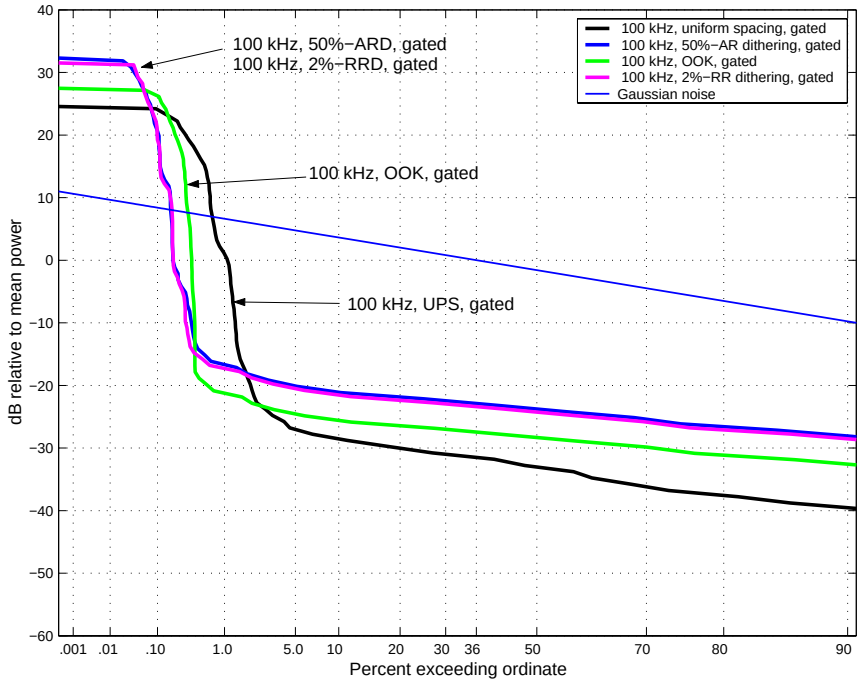


Figure C.3.15. APDs of 100-kHz PRF, gated UWB signals measured in a 20-MHz bandwidth.

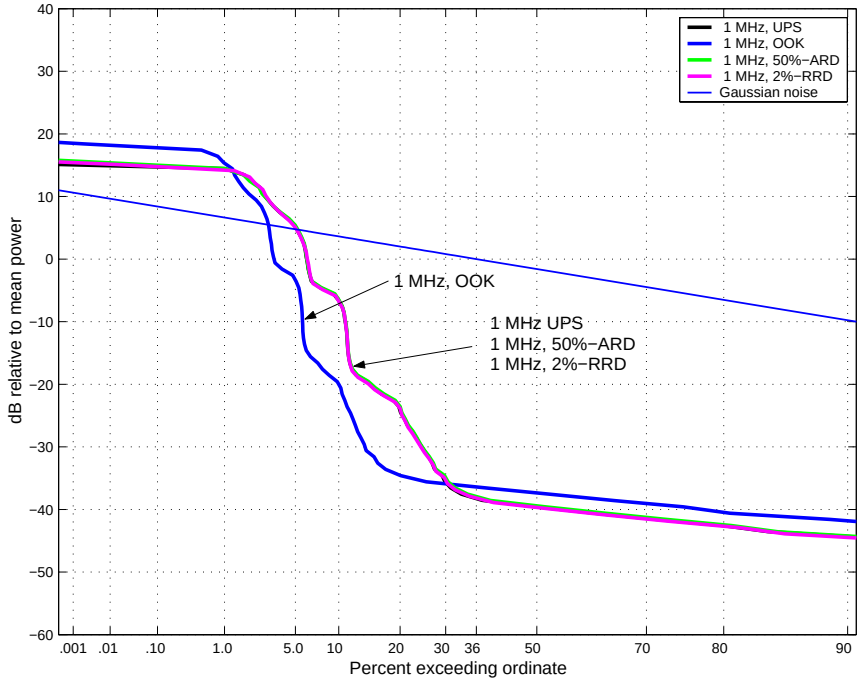


Figure C.3.16. APDs of 1-MHz PRF, non-gated UWB signals measured in a 20 MHz bandwidth.

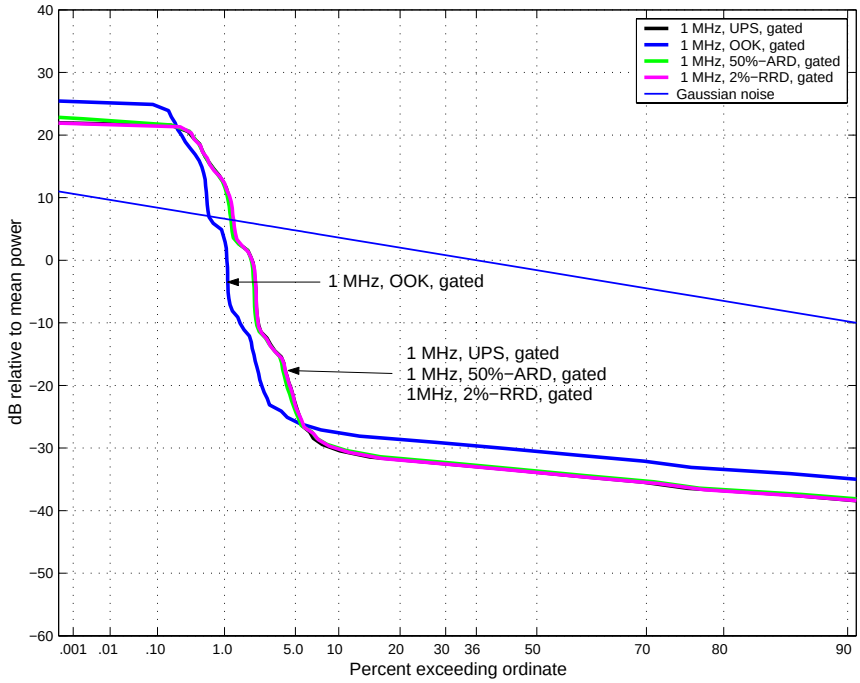


Figure C.3.17. APDs of 1-MHz PRF, gated UWB signals measured in a 20-MHz bandwidth.

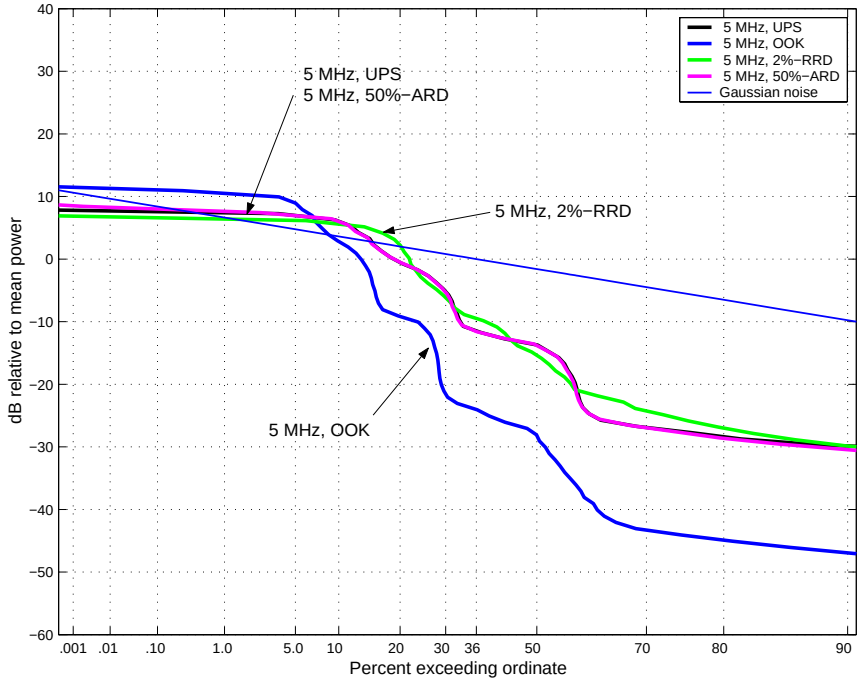


Figure C.3.18. APDs of 5-MHz PRF, non-gated UWB signals measured in a 20-MHz bandwidth.

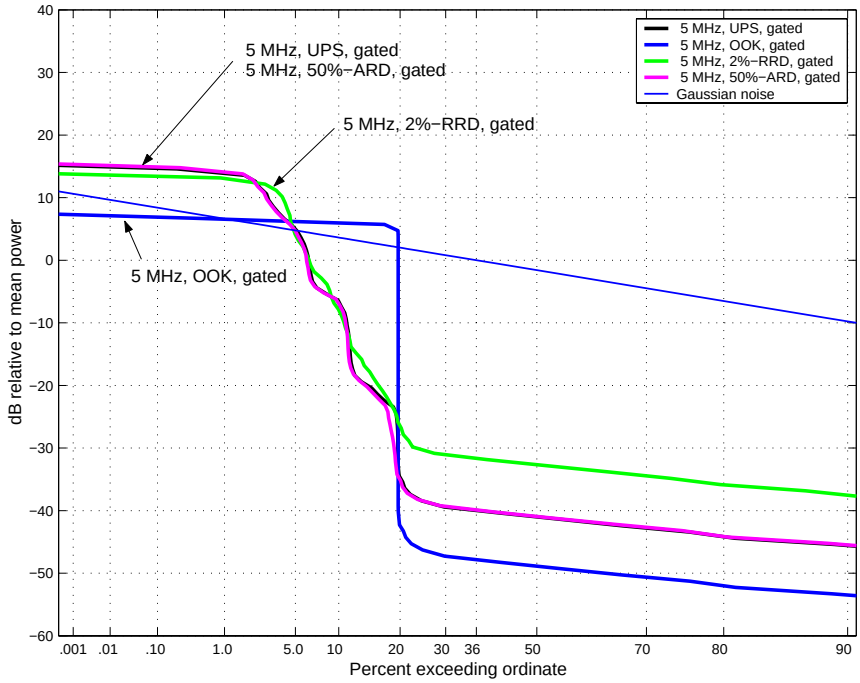


Figure C.3.19. APDs of 5-MHz PRF, gated UWB signals measured in a 20-MHz bandwidth.

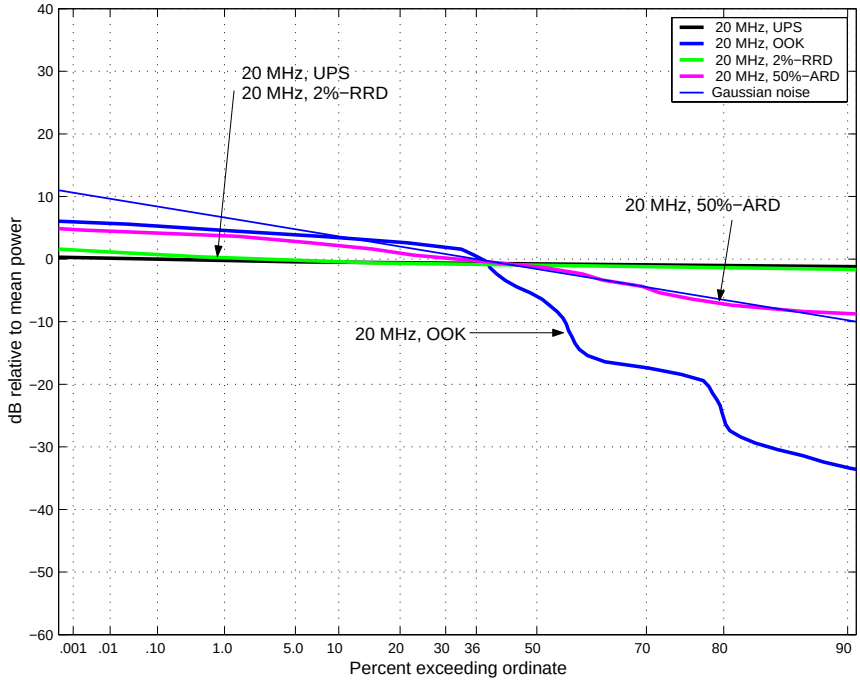


Figure C.3.20. APDs of 20-MHz PRF, non-gated UWB signals measured in a 20 MHz bandwidth.

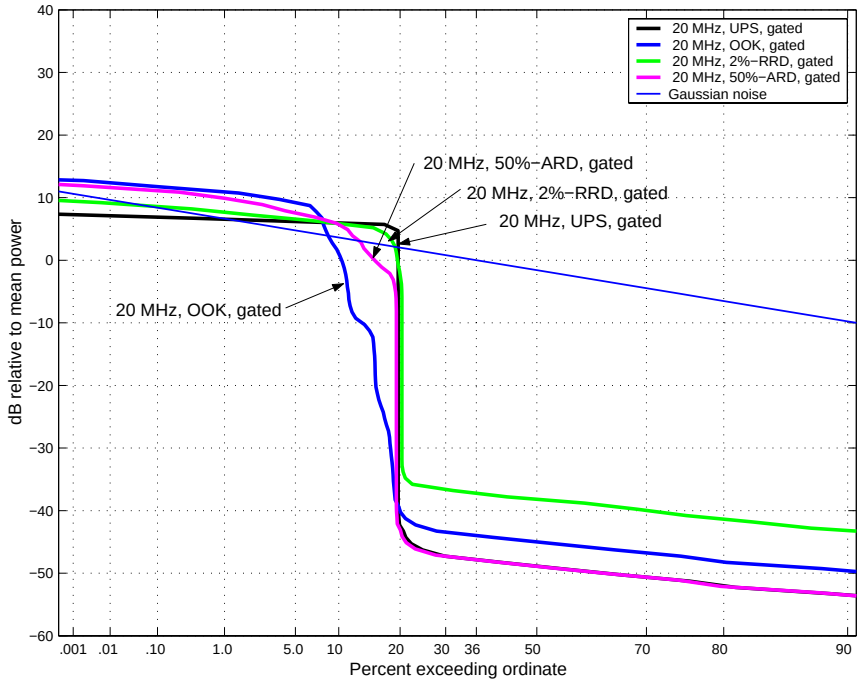


Figure C.3.21. APDs of 20-MHz PRF, gated UWB signals measured in a 20-MHz bandwidth.

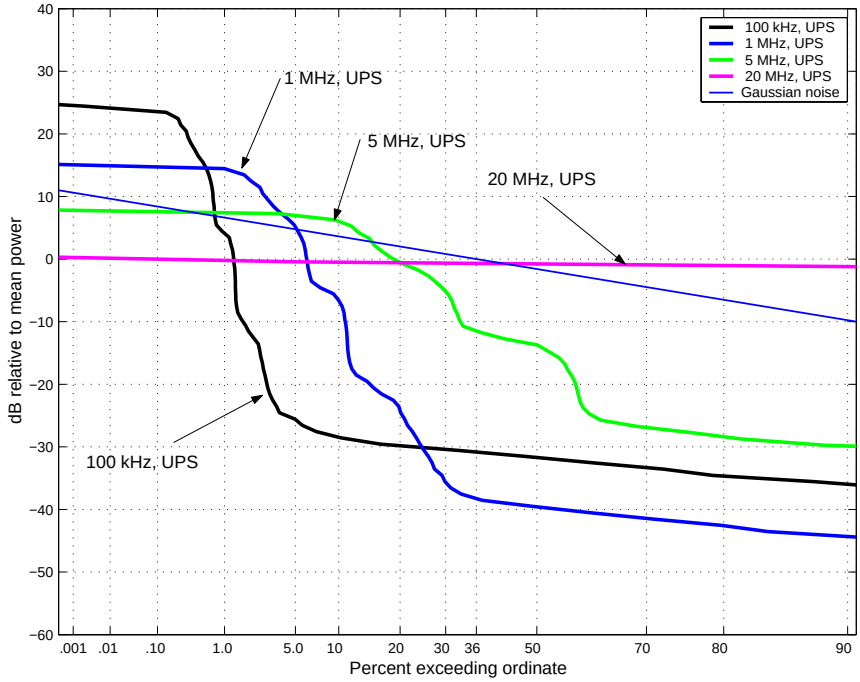


Figure C.3.22. APDs of UPS, non-gated UWB signals measured in a 20-MHz bandwidth.

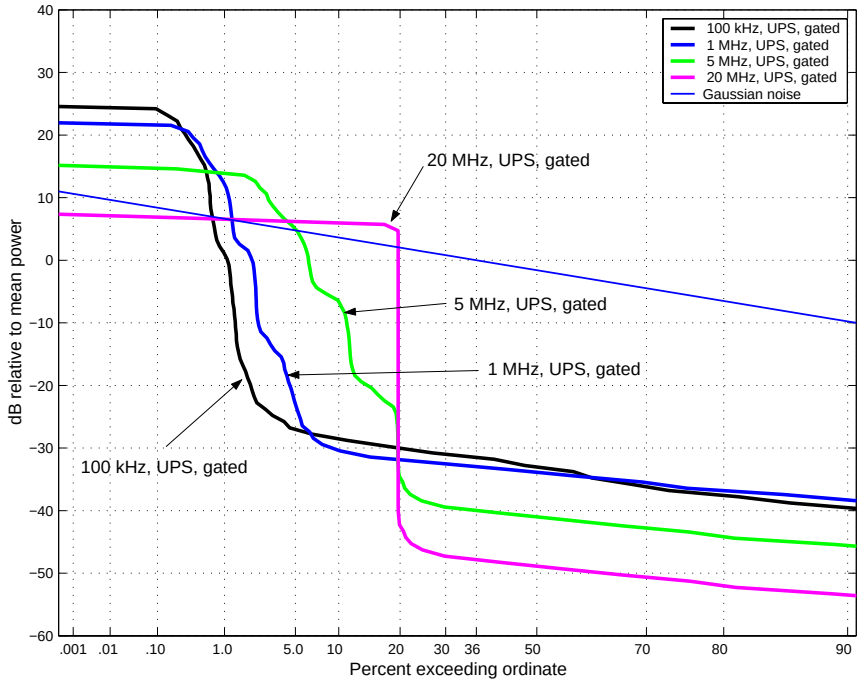


Figure C.3.23. APDs of UPS, gated UWB signals measured in a 20-MHz bandwidth.

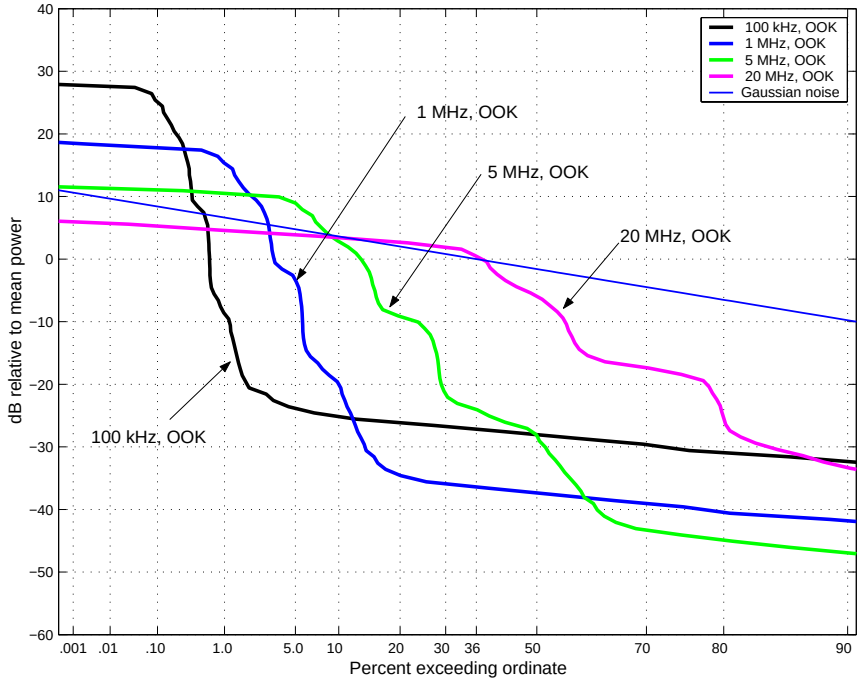


Figure C.3.24. APDs of OOK, non-gated UWB signals measured in a 20-MHz bandwidth.

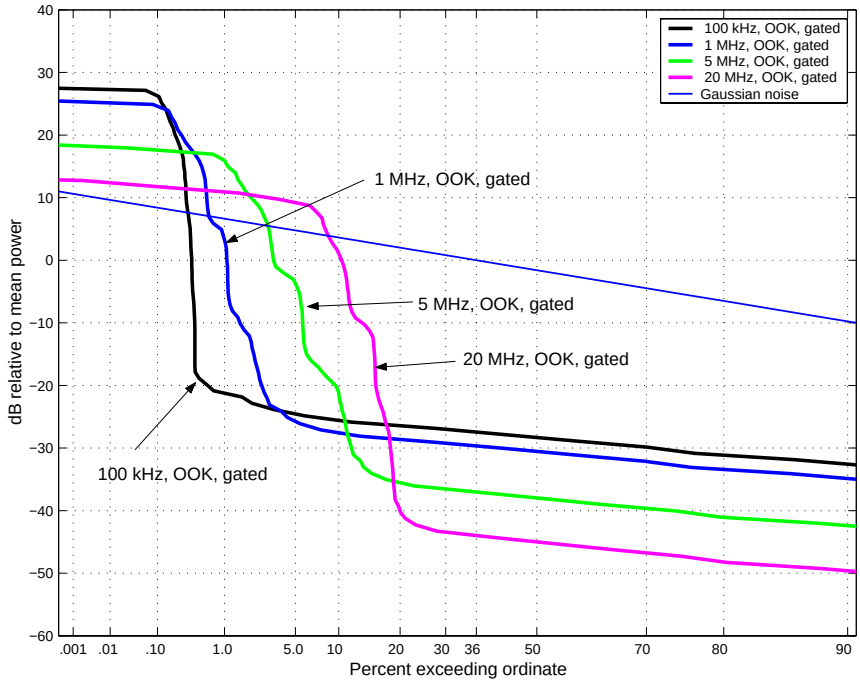


Figure C.3.25. APDs of OOK, gated UWB signals measured in a 20-MHz bandwidth.

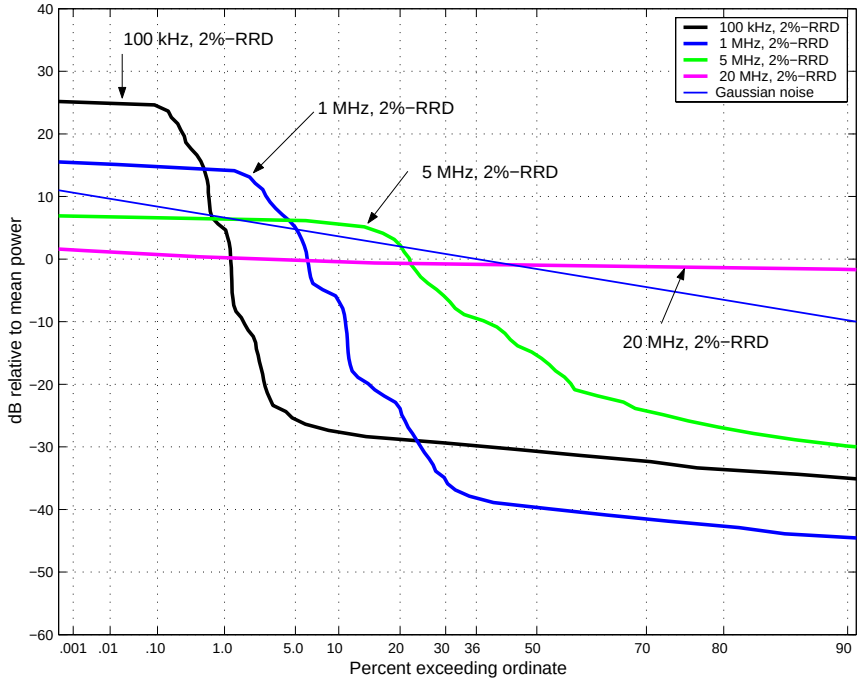


Figure C.3.26. APDs of 2%-RRD, non-gated UWB signals measured in a 20-MHz bandwidth.

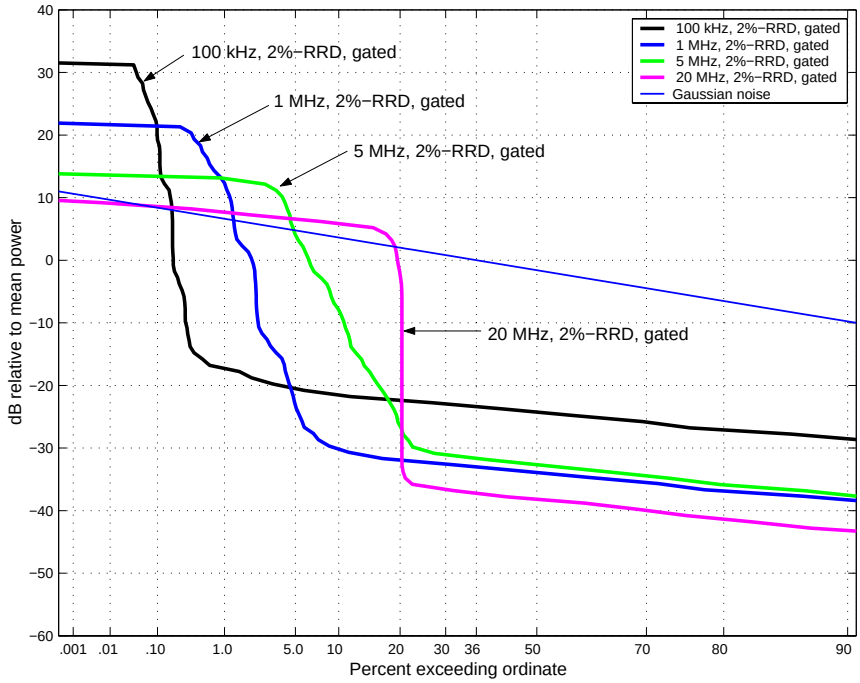


Figure C.3.27. APDs of 2%-RRD, gated UWB signals measured in a 20-MHz bandwidth.

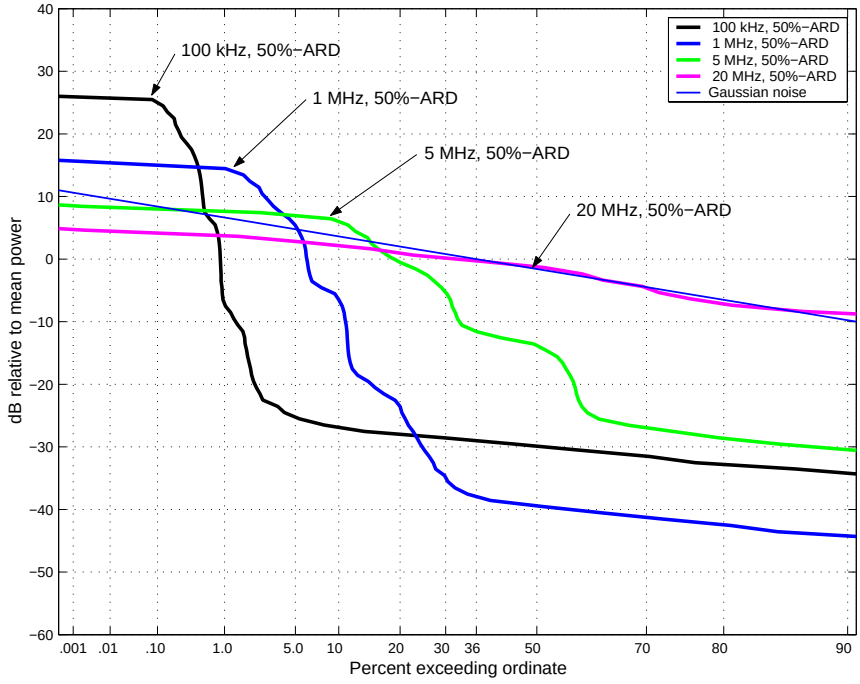


Figure C.3.28. APDs of 50%-ARD, non-gated UWB signals measured in a 20-MHz bandwidth.

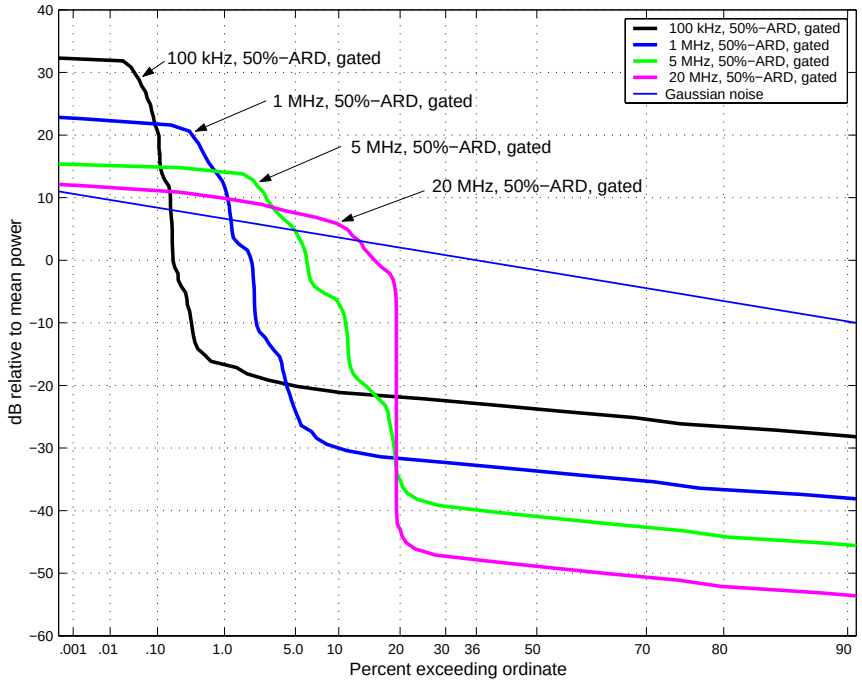


Figure C.3.29. APDs of 50%-ARD, gated UWB signals measured in a 20-MHz bandwidth.

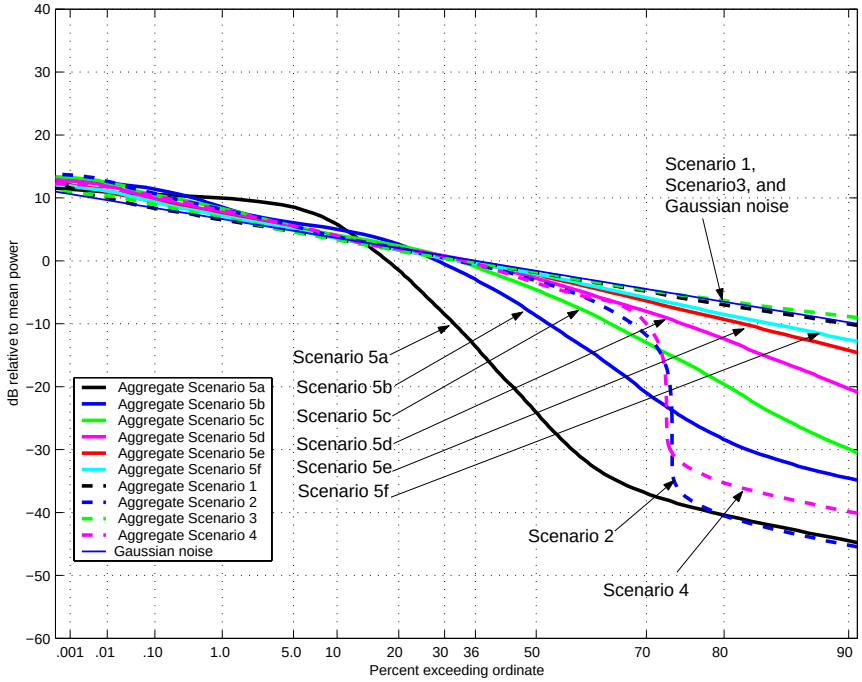


Figure C.3.30. APDs of aggregate UWB signals measured in a 3-MHz bandwidth.

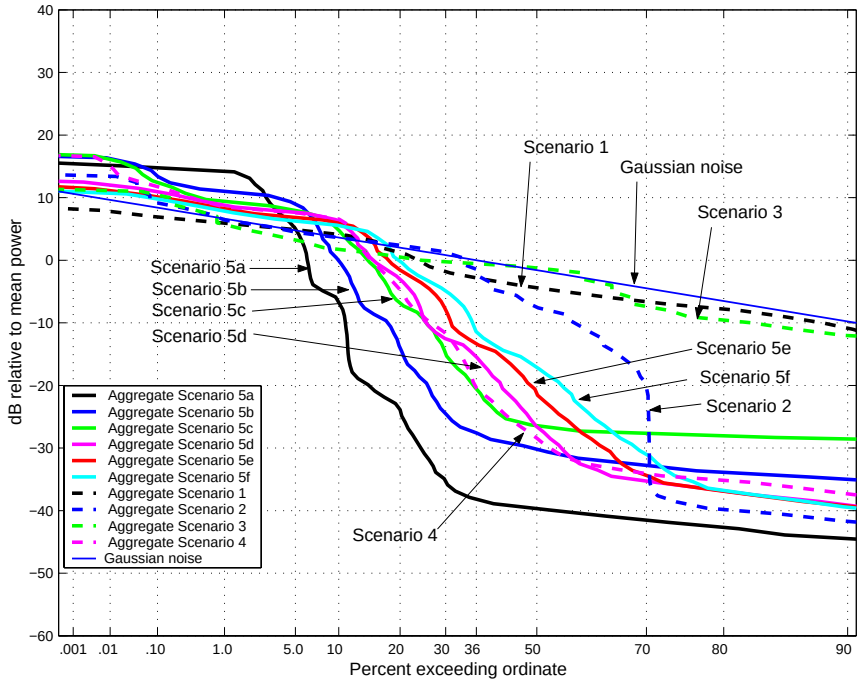


Figure C.3.31. APDs of aggregate UWB signals measured in a 20-MHz bandwidth.